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Computer Integration of Hydrodynamics Equations for Heat Pipes

The problem:

A method was needed to help describe the hydrodynamics of a high-performance heat pipe.

The solution:

The program MULTIWICK was developed to numerically integrate the differential equations used to describe the heat pipe.

How it's done:

MULTIWICK is a computer program to numerically integrate differential equations that describe the hydrodynamics of high-performance heat pipes that have multiple flow paths for condensate to return to the evaporator regions. The program MULTIWICK is applicable to the following types of flow paths:

a. Wick — a single piece of porous material that runs the length of the heat pipe. It is usually either a layer that lines the inner wall of the heat pipe or a diametral slab.
b. Arteries — porous-walled conduits that run the length of the heat pipe and are closed at the evaporator end. Primed arteries provide low flow resistance and a high capillary pressure.
c. Excess-Liquid Reservoirs — axial channels that primarily provide excess-liquid control in zero-gravity operation (excess liquid resides in the reservoirs rather than in a vapor-space slug). An excess-liquid reservoir can be either a porous-walled open-ended tube or a channel formed by a tube in close proximity to the intersection of a wick and the heat-pipe wall. Unlike arteries, reservoirs usually do not remain filled throughout their entire length.
d. Fillets — liquid that forms in corners due to surface tension. The fillet size at a given point along its length is automatically set by the vapor/liquid pressure difference at that point.
e. Bilge — liquid that lies in the bottom of a heat pipe operating in a gravitational field.
f. Circumferential Grooves — grooves that distribute liquid under the action of surface tension across the inner surface of the heat-pipe wall.
g. Vapor Spaces — areas that serve as flow paths for vapor to return to the condenser sections.

MULTIWICK has five operational modes that provide the user flexibility in answering crucial heat-pipe design questions. In the preliminary analysis of a new heat pipe, the designer uses one operational mode (Mode No. 1) to find the optimum amount of working fluid and the corresponding maximum heat-transfer rate for a specific condition. (The optimum amount of working fluid is defined as the amount that provides the greatest heat-transfer rate without resulting in a liquid slug in a vapor space.) Once the amount of working fluid has been determined, the user can then find the maximum heat-transfer rate at any other operating condition for that amount of fluid (Mode No. 4).

In Mode No. 2, the user specifies both the amount of working fluid and a heat-transfer rate. MULTIWICK then calculates the liquid distribution and the variation of the vapor/liquid pressure difference in the heat pipe. Such a calculation is useful, for example, to find the length of liquid slugs in vapor spaces that can result from liquid expansion at higher operating temperatures.

In the case of an arterial heat pipe, MULTIWICK has two additional operational modes that calculate the maximum heat-transfer rate under which arteries will prime. One is for an optimum amount of fluid for priming (Mode No. 3); the other is for a specified amount (Mode No. 5).

(continued overleaf)

The MULTIWICK user specifies the heat input and rejection distribution. The heat pipe is divided into sections, and the fraction of the total heat throughout is specified for each section. Thus the program is not limited to heat pipes with only one evaporator, one adiabatic, and one condenser section.

The MULTIWICK program incorporates a mathematical model of flow through fibrous wicks that includes the following effects:

a. Meniscus Recession — the reduction of the flow area due to the menisci at the wick surface attaining a higher curvature with increasing vapor/liquid pressure difference.

b. Partial Saturation — the emptying of the progressively smaller pores of the wick as the vapor/liquid pressure difference approaches the critical value where the wick fails.

c. Hysteresis — the relationship between the level of saturation of the wick and the vapor/liquid pressure difference, depending on whether the pressure difference has increased or decreased. The MULTIWICK user, therefore, specifies whether the heat pipe starts from a state where the wick is initially saturated or, as in the case after a burnout, from a state where the wick in the evaporator region has dried out.

The user may also elect a simple model of fully-saturated wick operation that does not include the above effects.

Notes:

1. This program was written in FORTRAN IV for the CDC 6000-series computer.
2. Inquiries concerning this program should be directed to:

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   Reference: GSC-12009

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